7.4 PRECIPITATION DISTRIBUTION FROM LANDFALLING TROPICAL CYCLONES OVER THE SOUTHEAST UNITED STATES COAST

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1. Introduction

Landfalling tropical cyclones represent one of the greatest forecast challenges today, due to the inherent unpredictability in wind speed, storm surge, and precipitation. Of these, rainfall – and its associated dangerous inland flooding – can be most greatly modified by outside influences from synoptic and mesoscale systems, especially in relation to coastal features. Two case studies are presented here for comparison; Tropical Storm Marco (1990), which was responsible for 7 deaths and \$57 million in damage in the southeast United States (Mayfield and Lawrence, 1991) and Tropical Storm Jerry (1995), responsible for 6 deaths and \$26.5 million in damage (Lawrence et al., 1996) over the same region. Rainfall from each of these systems was affected by the presence and location of a coastal front, orographic enhancement, and cold air damming against the Appalachians. The purpose of this paper is to further examine these coastally driven features to better explain each storm's precipitation distribution.

2. Data and Methodology

Gridded (0.25° x 0.25°) daily precipitation was obtained from the NCEP Unified Precipitation Dataset (UPD), a 24 h (1200 UTC to 1200 UTC) accumulated total over the United States. Storm track data is from the National Hurricane Center's best track positions. Synoptic upper-air data is from the NCEP/NCAR Global Reanalysis on a 2.5° x 2.5° grid (Kalnay et al., 1996; Kistler et al., 2001). Surface data over land are from NCEP's Automated Data Processing (ADP) Global Surface Observation dataset and the US Air Force's DATSAV3 dataset, while marine surface data is from the International Comprehensive Ocean-Atmosphere Data Set (I-COADS). The General Meteorological Package (GEMPAK) was used to prepare most of the plots shown here.

3. Storm Track and UPD Analyses

Tropical Storm Marco (Fig. 1) originated off the coast of Cuba around 1200 UTC 9 October 1990. From there, it traveled slowly northwestward, tracking along the west coast of the Florida Peninsula, with its intensity increasing to tropical storm force. Marco began to weaken slightly just before it made complete landfall near Cedar Key, Florida around 0000 UTC 12 October.

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From there, the weakening cyclonic disturbance tracked as a tropical depression through Georgia and South Carolina, where it eventually stalled, weakened, and dissipated soon after 1200 UTC 13 October.

Figure 1 shows Marco's total UPD precipitation from 1200 UTC 9 October through 1200 UTC 13 October 1990, as well as the archived best track. Over 25 cm of rain fell at some locations within this four day period. A look at daily UPD analyses provides further insight into the observed rainfall distribution. Figure 2 shows a plot of 24 h precipitation ending 1200 UTC 11 October. Note the northward bulge in heavy rainfall (totals over 100 mm) which stretches through North Carolina and Virginia for this 24 h period. However, at 1200 UTC 11 October, Marco is west of Tampa, Florida, so this northern precipitation maximum can not be directly imputed to Marco.

Tropical Storm Jerry (Fig. 3) was a longer lived storm than Marco, but shared many common track characteristics with the earlier storm. Soon after attaining tropical storm status, Jerry made its first landfall near Jupiter, Florida, around 1200 UTC 23 August. It then crossed the Florida Peninsula, and emerged into the Gulf of Mexico as a tropical depression. From there, Jerry turned northward and made a second landfall along the eastern end of the Florida Panhandle. After landfall Jerry slowly moved north and east into Georgia and South Carolina, where it weakened.

Figure 3 shows the storm total precipitation for Jerry from 1200 UTC August 23 to 1200 UTC August 28 1995. In this case, the regions of heavy rainfall totals do not seem too far removed from the storm's track. Precipitation stays to the east of the Appalachian ridge axis, suggesting orographic enhancement is important in this case. An examination of the 24 hour total UPD precipitation ending 1200 UTC August 24 (Fig. 4) shows a secondary precipitation maximum along the Georgia/South Carolina coast, while the storm is still over central Florida.

4. Synoptic Analyses

At 0000 UTC 9 October 1990, the decaying Hurricane Klaus approached the United States coast. Although Klaus was no longer tracked as a tropical system after 1200 UTC 9 October, high θ_e air at 925 hPa associated with the storm continued to move toward the southern East Coast (not shown). At the same time, a large-scale positively-tilted trough east of the Rockies dominates the flow over the eastern two-thirds of the United States. At 1200 UTC 11 October, a fairly strong 200 hPa jet stretches roughly along the ridge axis (Fig. 5), placing the equatorward entrance region over the the southeast Atlantic states. The combination of the high θ_e air remnants from Klaus with this upper level forcing for ascent partially explains the northward bulge of precipitation seen in Fig. 2.

Heavy precipitation was recorded over Florida, Georgia and the Carolinas through most of Marco's lifetime. At 1200 UTC 12 October, the strong 200 hPa jet right-entrance region remained over the southeast United States (not shown). Through this period and the next 24 h, Marco seems to be in good position with the 200 hPa jet for a potential extratropical transition (ET, Jones et al., 2003), which would send Marco moving rapidly to the north and east. At the same time, Hurricane Lili approaches the United States coast quickly from the east. Marco and Lili seem to undergo binary interaction (Prieto et al., 2003), which would cause Marco to tend toward the south and east, while Lili would be forced to the north and west. This is consistent with the track of both Marco and Lili, and partially explains why Marco did not undergo an extratropical transition and dissipated over South Carolina.

In Jerry's case, synoptic scale features do not play an important role. The 200 hPa jet is far to the north of Jerry at 0000 UTC 24 August 1995 (Fig. 6). The pattern north of Jerry through its lifetime is dominated by a weak ridge pattern. This means that warm and moist air near the surface away from the storm center is less likely to translate into rain, since the additional forcing for ascent is not present in this case. Lacking upper air support and the high θ_e air from another tropical system, the precipitation in the southeast US must be from Jerry and its effects.

5. Surface Analyses

Mesoscale surface features, defined and positioned by the coastline, also play very important roles in both Marco's and Jerry's rainfall patterns. As is the case with many landfalling tropical cyclones, coastal orography can play a vital role in forecasting precipitation distribution. Before either Marco or Jerry reached Georgia and the Carolinas, the orientation and location of a coastal front induced by the storm proved to be very important. As Marco traveled northward, it began to induce a coastal front through onshore flow along the coast of Georgia and South Carolina. This boundary can be seen as a strong θ_e gradient at 0000 UTC 11 October, while Marco is still west of Fort Myers, Florida (Fig. 7). This coastal front would continue to be present as Marco moved northward. Thus, some of the heavy precipitation along the coast in Fig. 2 can be attributed to this coastal front. The strong θ_e gradient further inland in Fig. 7 (near the mountain axis) is the cold front from the synoptic system. The direction of flow between these two strong θ_e gradients is directed along the ridge axis toward the south. This is hypothesized to be a signal of cold air damming – in this case forced more by a low pressure system to the south more than a high pressure system to the north. Combine the strong moist onshore flow with the addition of lift from topography, and significant rainfall resulted, both from the early moisture from Klaus, and the rainfall directly from Marco as it moved further north.

Jerry, throughout most of its lifetime, was weaker than Marco; thus, one would expect a weaker coastal front boundary due to weaker convergence. This can be seen at 0900 UTC 24 August 1995 in the θ_e field (Fig. 8). Although no strong gradient can be seen along the coast, the slight change of θ_e combined with the wind shift along the coast provide for the northern precipitation maximum seen in Fig. 4. After Jerry's second landfall, the warm, moist air brought onshore was forced upward due to orographic enhancement. Since the upper level flow did not force any significant ascent, flow up the Appalachians was the dominant source of lift. Most of the precipitation after Jerry's second landfall shows distinct maxima where upslope wind (from the ocean) is greatest (not shown).

6. Summary

Tropical Storms Marco and Jerry are two examples of weak tropical cyclones where coastal features greatly influence overall precipitation distribution. Although the storms had similar tracks and intensities, the final rainfall distributions were quite different. In Marco's case, upper level ascent combined with a very warm and moist atmosphere to cause significant rainfall far to the north of Marco. Further south, the strong coastal front created by Marco's circulation augmented the precipitation near the coastline. Jerry also saw precipitation augmentation from a coastal front and orographic enhancement, but the heaviest rainfall totals were much closer to the storm center.

7. Acknowledgments

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8. References

Bosart, L. F., C. J. Vaudo, and J. H. Helsdon Jr., 1972: Coastal Frontogenesis. *J. Appl. Meteor.*, **11**, 1236-1258.

Jones, S. C., and Coauthors, 2003: The Extratropical Transition of Tropical Cyclones: Forecast Challenges, Current Understanding, and Future Directions. *Wea. Forecasting*, **18**, 1052-1092.

Kalnay, E., and Coauthors, 1996: The NCEP/NCAR 40-Year Reanalysis Project. *Bull. Amer. Meteor. Soc.*, **77**, 437-471.

Kistler, R., and Coauthors, 2001: The NCEP/NCAR 50-Year Reanalysis: Monthly Means CD-ROM and Documentation. *Bull. Amer. Meteor. Soc.*, **82**, 247-267.

Lawrence, M. B., B. M. Mayfield, L. A. Avila, R. J. Pasch, and E. N. Rappaport, 1998: Atlantic Hurricane Season of 1995. *Mon. Wea. Rev.*, **126**, 1124-1151.

Mayfield, M., and M. B. Lawrence, 1991: Atlantic Hurricane Season of 1990. *Mon. Wea. Rev.*, **119**, 2014-2026.

Prieto, R., B. D. McNoldy, S. R. Fulton, and W. H. Schubert, 2003: A Classification of Binary Tropical Cyclone-Like Vortex Interactions. *Mon. Wea. Rev.*, **131**, 2656-2666.

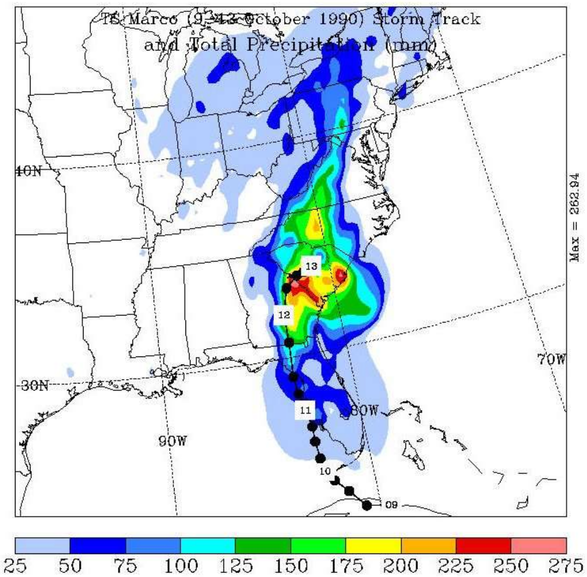

Figure 1. Storm Total UPD Precipitation (mm) 1200 UTC 9 October to 1200 UTC 13 October 1990.

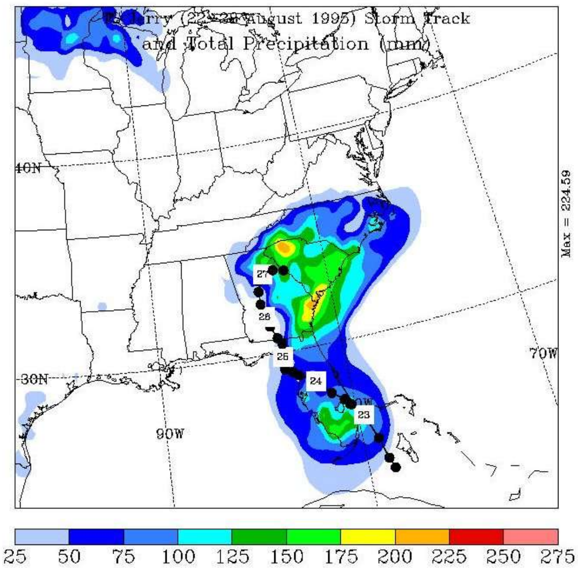

Figure 3. Storm Total UPD Precipitation (mm) 1200 UTC 22 August to 1200 UTC 28 August 1995.

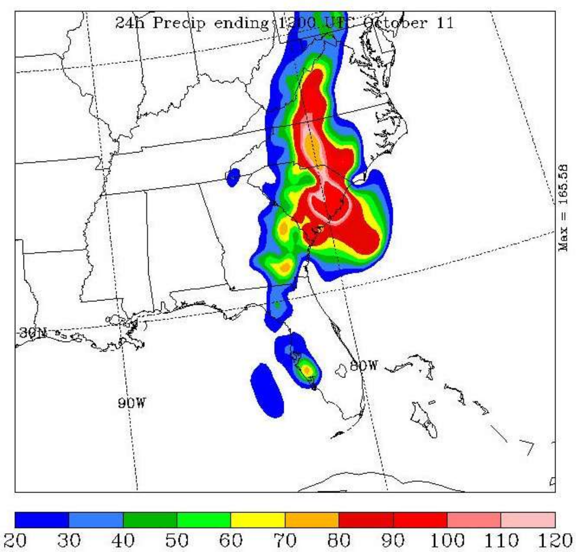

Figure 2. UPD precipitation (mm) from 1200 UTC 10 October to 1200 UTC 11 October 1990.

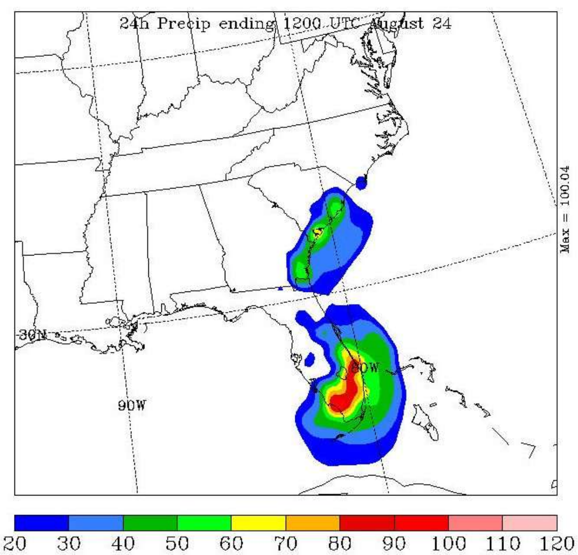

Figure 4. UPD precipitation (mm) from 1200 UTC 23 August to 1200 UTC 24 August 1995.

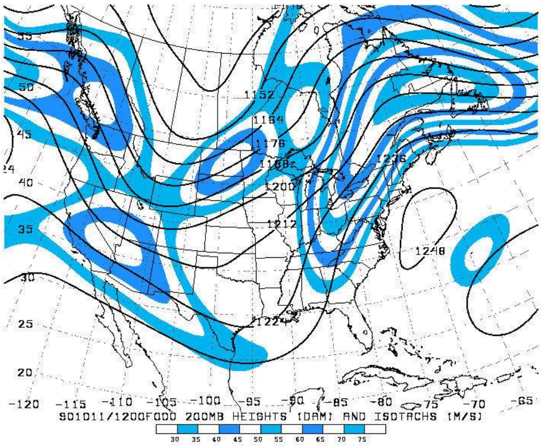

Figure 5. 200 hPa isotachs (m s^{-1}, shaded above 30 m s^{-1}) and heights (dam, solid contours) at 1200 UTC 11 October 1990.

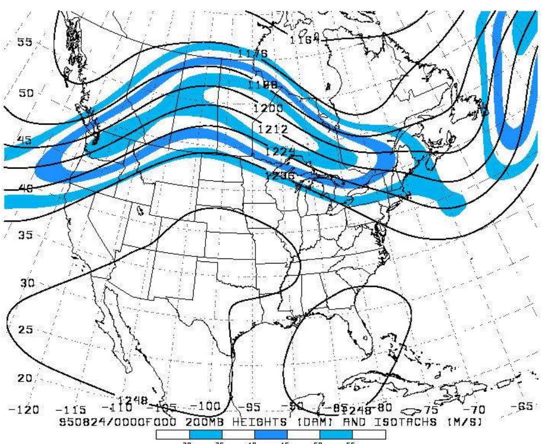

Figure 6. 200 hPa isotachs (m s^{-1}, shaded above 30 m s^{-1}) and heights (dam, solid contours) at 0000 UTC 24 August 1995.

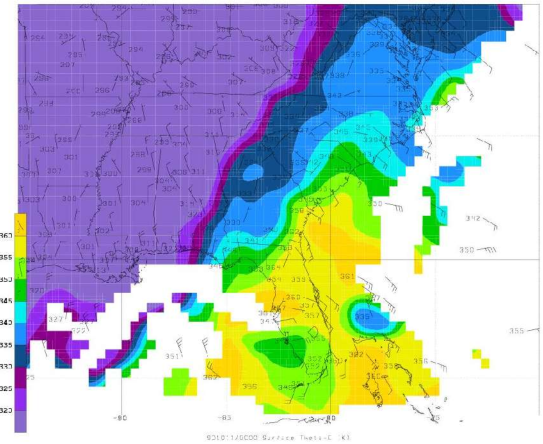

Figure 7. Objectively analyzed surface θ_e for 0000 UTC 11 October 1990.

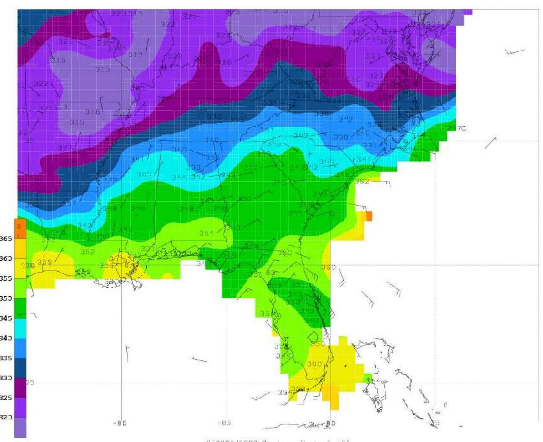

Figure 8. Objectively analyzed surface θ_e for 0900 UTC 24 August 1995.